Particle response studies

P. Silva (CERN)

HGCAL sofware meeting

Tuesday, 2nd September 2014

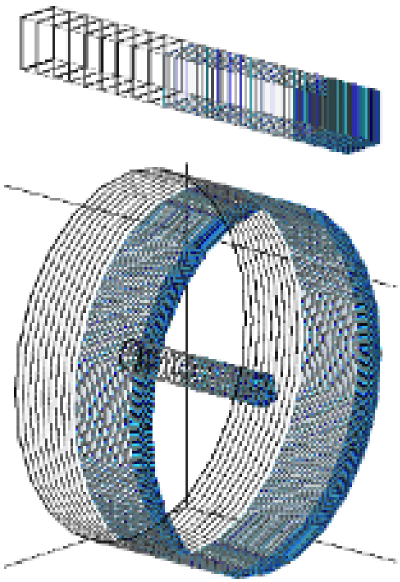
Scope

- **Basis for optimal calorimeter response**
  - How do the different particles interact with the sensitive and passive elements?
  - Where do they interact?
  - What are the characteristics of the showers?
  - What is the calibration needed to apply to the reconstructed hits?
  - What is the expected resolution at each step: simulation, digitization, reconstruction, PF?
  - How do the simulation models compare to the data?
- Our **current strategy** is to **compare two independent benchmarks**
  - standalone simulation versus CMSSW full simulation
  - standalone is flexible to compare with previous simulations/measurements from CALICE
  - CMSSW integrates the final geometry, material in front of HGCal and magnetic field
- Next slides: highlight some of the current results and next steps regarding these studies

Simulation setups

Standalone simulation

- **Pursued in parallel with respect to CMSSW**
  - highly flexible to compare to benchmarks (CALICE), simulate test-beam
  - independent cross-check: debugging tool for CMSSW
  - lightweight: for design optimisation



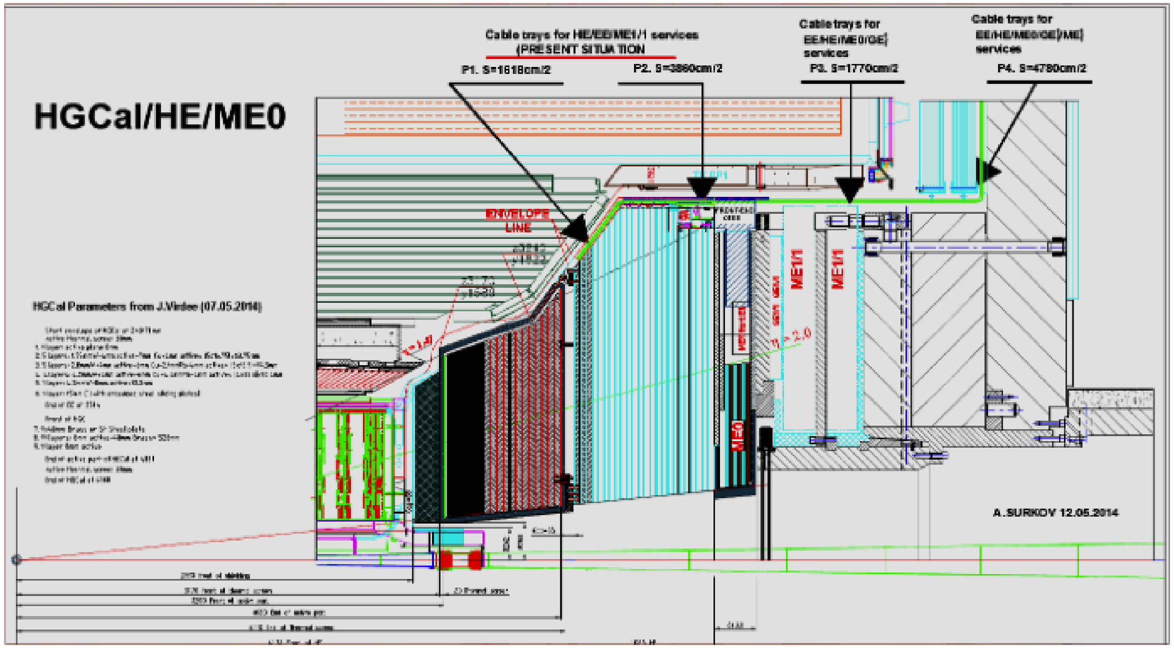
P. Silva, A.-M. Magnan

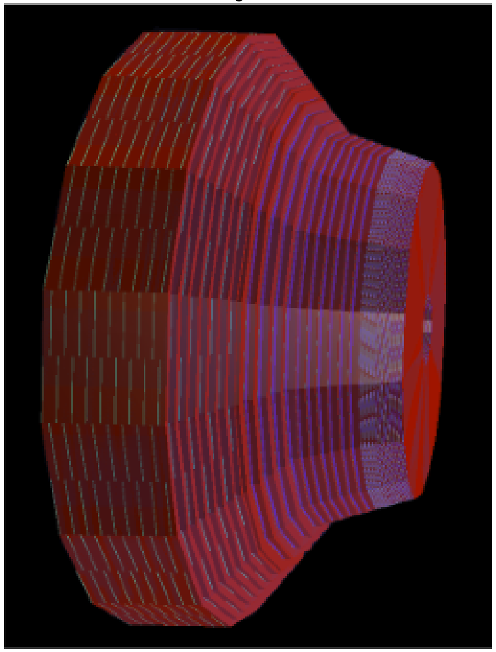
- Code is available in git-hub
  - https://github.com/pfs/PFCal/tree/master/PFCalEE
  - implements simple stack geometry or a full endcap
  - based on "sampling sections": very easy to vary material, absorber width etc...
  - particle gun or HepMC-based interfaces used for the simulation
  - output written in simple tree, with collection of HGC SimHits
  - easy to analyze
  - maintain with the same Geant4 version and physics lists used in CMSSW

CMSSW simulation

- Implements two possible geometries in CMSSW
  - concept geometry (v4) and TP description (v5) – see link
  - radial ganging to be implemented

S. Banerjee, V. Andreev



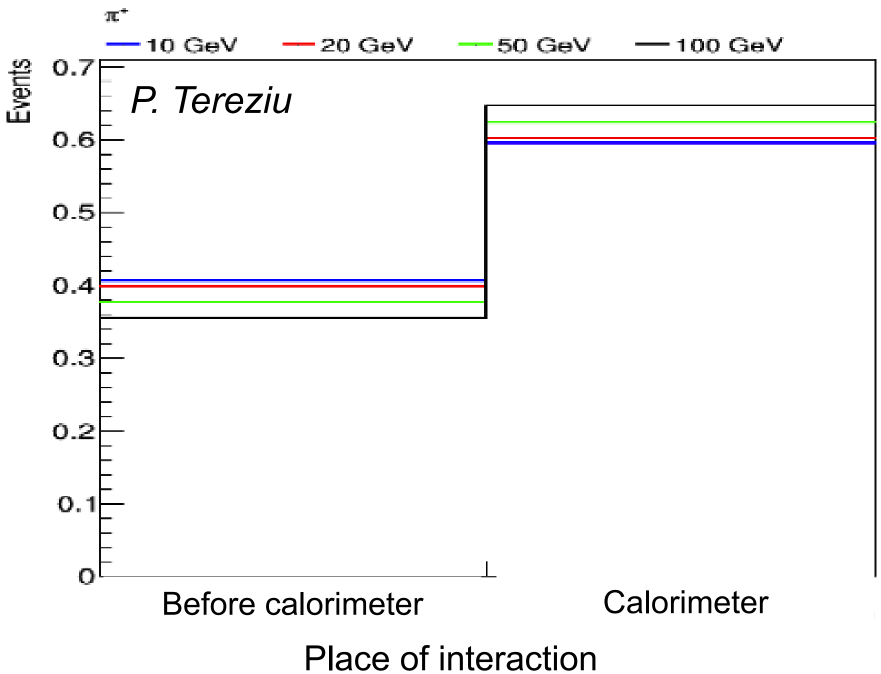


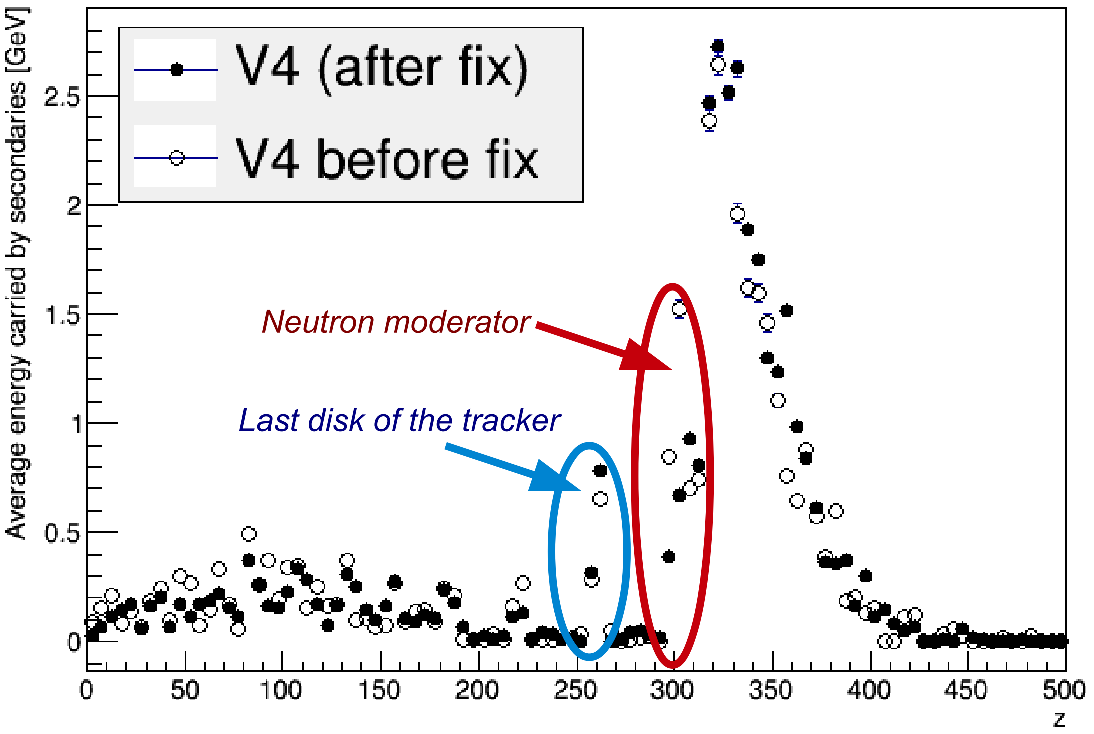
- All steps SIM-DIGI-RECO-PF are fully linked and operational
  - Commissioning every step and improving implementation

    e.g. alignment of the hits, material budgets, calibration, expected response, noise estimate,...
  - Crucial for optimal performance estimate of HGCal

Recent issues with CMSSW simulation

- **[Material overburden in front of HGCal]** besides the tracker, neutron moderator
- First implementation ~$0.8X_0$ and ~0.2λ
- Consequences:
  - many conversions + early π interactions
  - e.m. calibration with large 1st EE layer weight



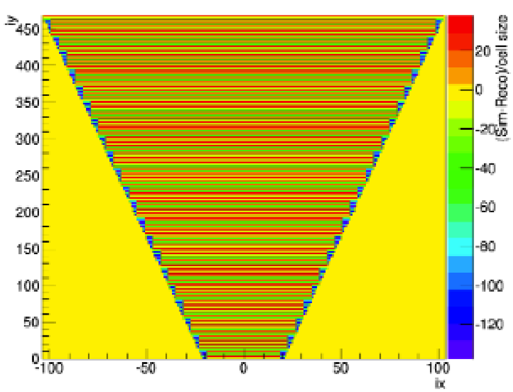


- Fix removing Al volumes (poliethylene only) : impact on performance at high PU?

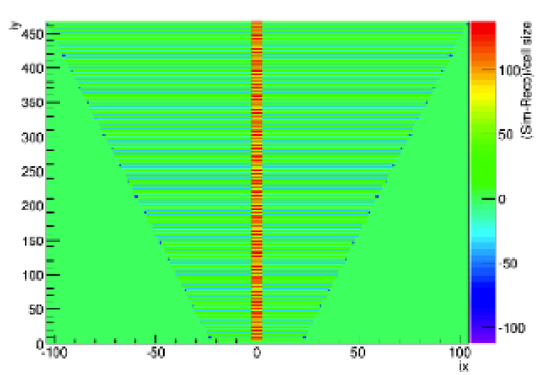
Recent issues with CMSSW simulation - II

- **[Jumping hits]** Identified from muons travelling near boundaries of a sector
- Common to EE, HEF and HEB
  - not declaring region as dead zone properly
  - evaluating cell limits at wrong location
- Checks for PR#5132
  - require ganging to shift sim positions by a maximum of the new cell size : ok
  - all cells sequentially numbered : ok
  - dead zones properly flagged : ok so far
  - Handle properly HEB sectors: on-going

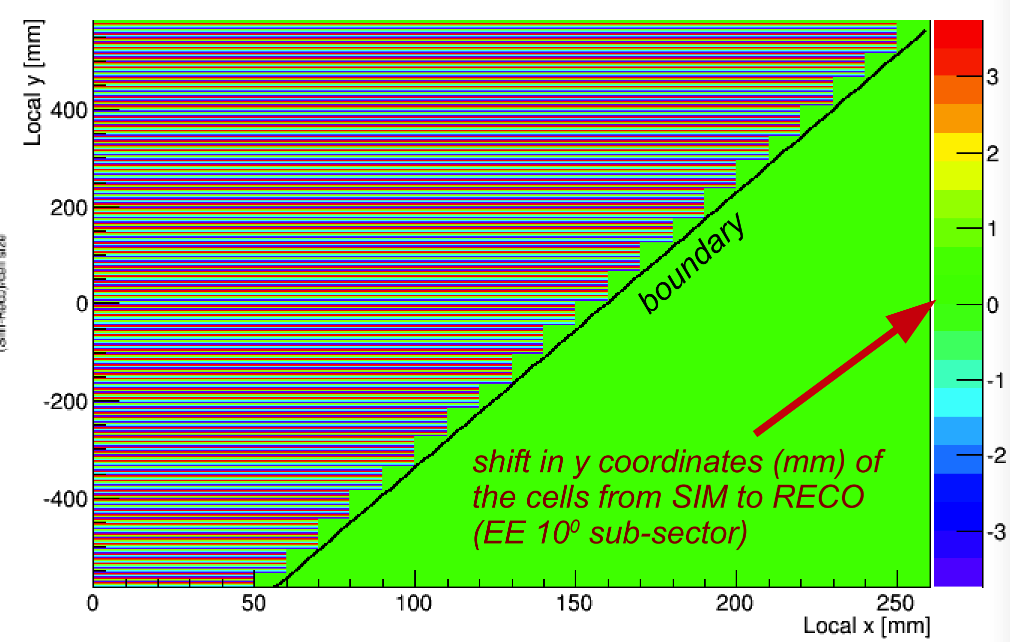
before fix v1



before fix v2



after fix



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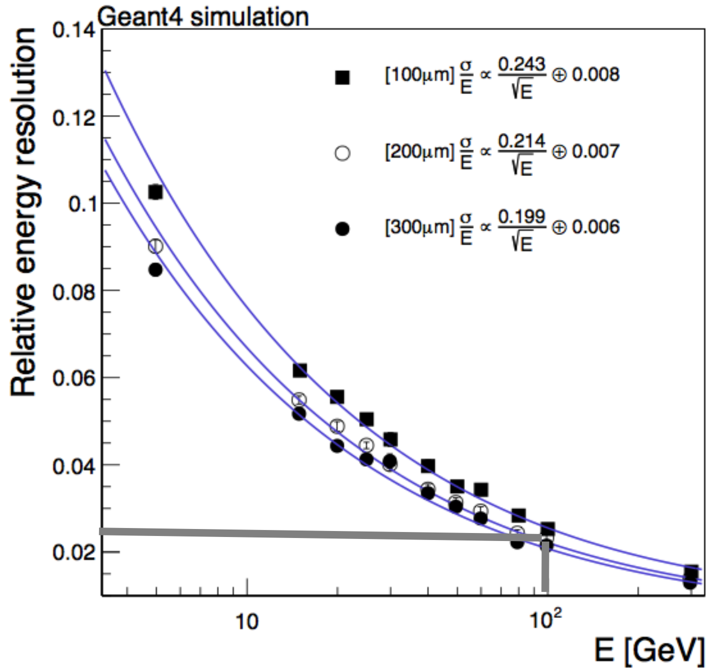
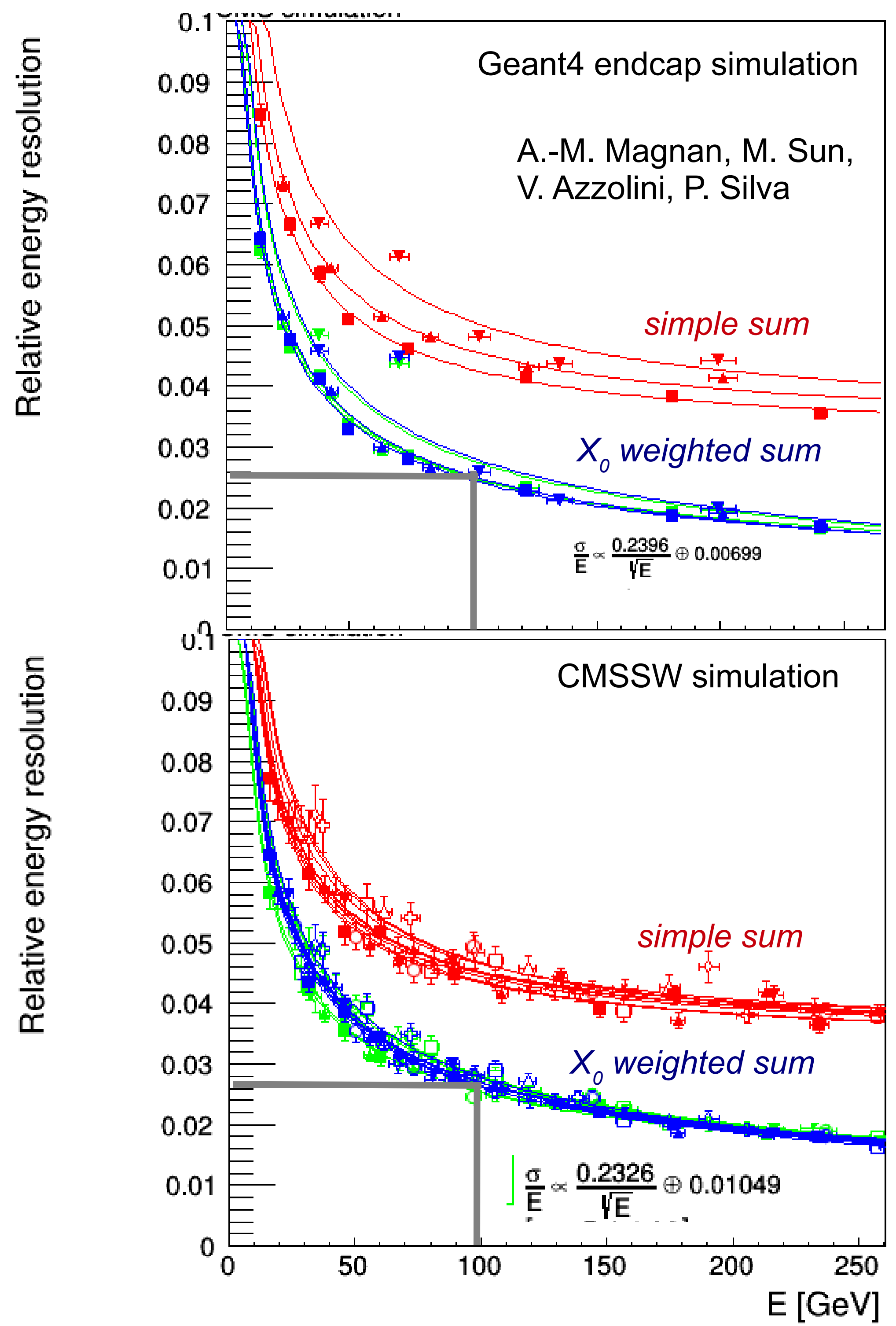
Particle response studies

Standalone → CMSSW



Electron gun studies

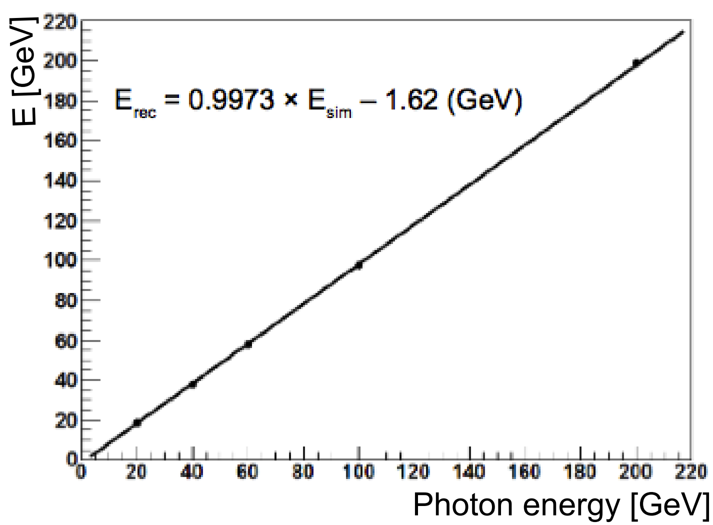
- Some degradation in endcap configuration with respect to 0 degrees incidence is η-independent
- Agreement between standalone and Geant4 verified at SimHit level
- *More studies in M. Sun's talk later*

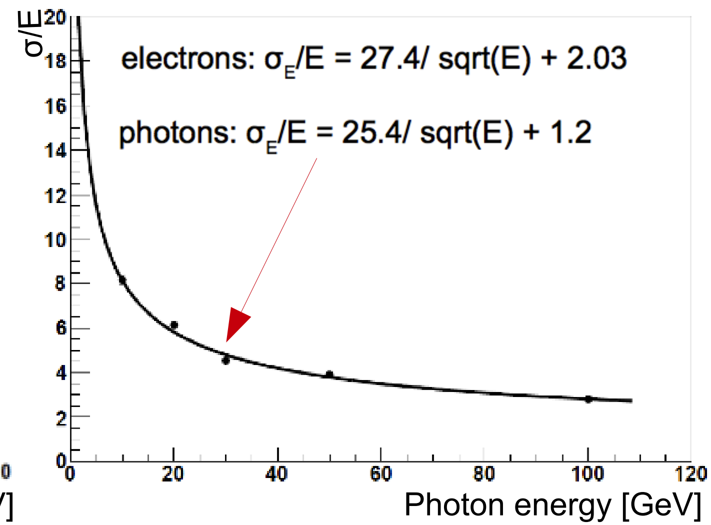


Electron resolution at reconstruction level

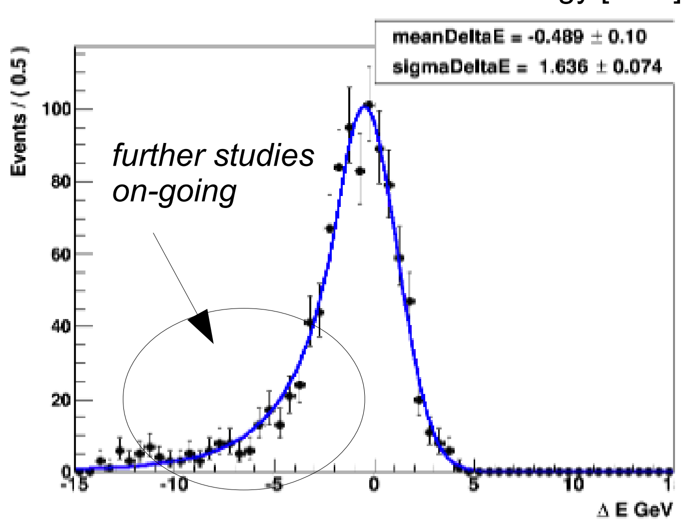
- First cross checks using RecHits (top) and PF photons (below for CMS PF)
  - Slight offset obtained in calibration, higher stochastic term and ~1% noise obtained
  - Observe non-symmetric responses after clustering
  - Further studies on-going to understand origin and correct the effects, where possible

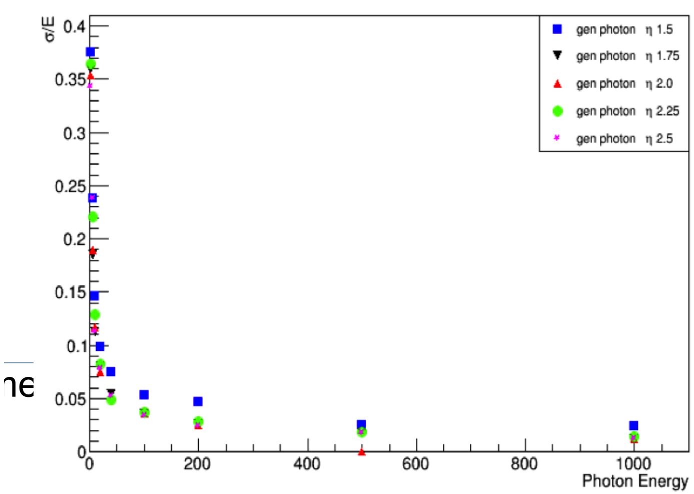
RecHit level
Trong Hieu Tran



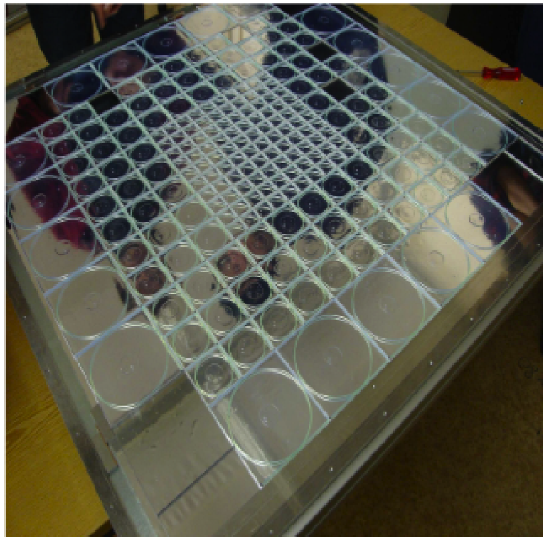


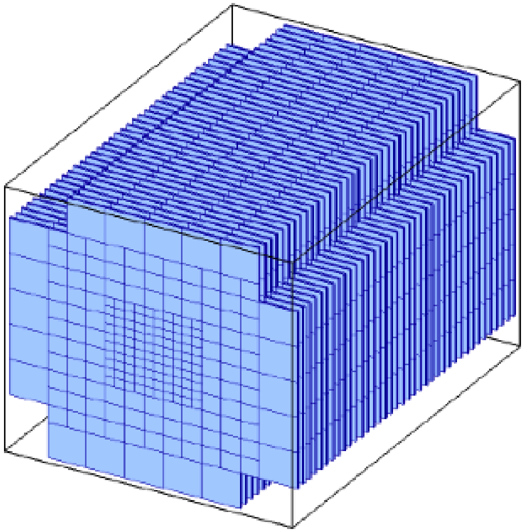
CMS PF level
M. Haytmyradov



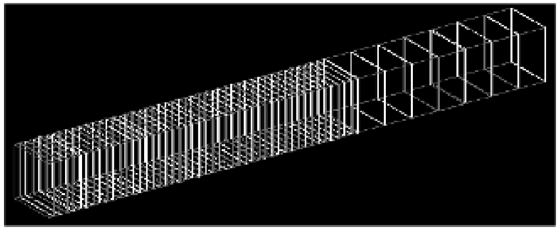


Towards hadronic calibration





A.-M. Magnan



- Details in A.-Marie's talk
- Validation against CALICE benchmark
  - using standalone setup
- Fe Absorber
  - 38 x 21 mm
  - Tail catcher: 9x 21mm +7x104mm
- Active material
  - 5-mm thick polystyrene scintillator
  - Lateral size $1x1m^2$
- Following JINST 7(2012) P09017, with help from M. Chadeeva (ITEP) and F. Simon (MPI)
- In the next slide highlight just current differences wrt to CMSSW implementation

Digitization model for pion resolution study

Timing cut of 150 ns

10

A.-M. Magnan

MC digitization procedure

Conversion of MC signal from MeV to MIP $\rightarrow e_{MIP}$

$\Downarrow$

Generation of random number of photoelectrons n_{pe}
from Poisson distribution with $\langle n_{pe} \rangle = e_{MIP} \cdot N_{pe}$ ($N_{pe} = 11$)

$\Downarrow$

Calculation of number of pixels n_{pixel} taking in account saturation and cross talk C:
$n_{pixel} = N_{total} \cdot \frac{(1-x)}{(1-C \cdot x)}$ where $x = \exp(-n_{pe}/N_{total})$, $C = 0.25$, $N_{total} = 1156$

$\Downarrow$

Generation of random signal n_{pixel}^{new} from Gaussian distribution $Gaus(\langle n_{pixel} \rangle, \sigma_G)$
where $\sigma_G = 3$ pixels (≈ 0.2 MIP)

$\Downarrow$

Recalculation from pixel to MIP: $e_{MIP}^{new} = \frac{N_{total}}{N_{pe}} \cdot \ln(\frac{N_{total} - C \cdot n_{pixel}^{new}}{N_{total} - n_{pixel}^{new}})$

$\Downarrow$

~~Adding noise hits from random event of pedestal run cell to cell~~

Adding 0.12 MIP gaussian noise everywhere

Adding 2.5% cross-talk / 3-cm edge

Implementing exact granularity

Marina Chadeeva, ITEP

CALICE week at IPN Lyon, September 2009

HEB digitization (CMSSW implementation)

Algorithm

- Timing cut for SimHits: 25 ns
- Convert MC signal from keV to MIP: N_{MIP}
- Generate random number of photoelectrons: $n_{pe} \sim \mathrm{Poisson}(N_{MIP} \cdot N_{pe/MIP})$ with $N_{pe/MIP} = 11$
- Compute number of pixels accounting for cross talk: $n_{pixels} = N_{total} \cdot \dfrac{1-x}{1-C \cdot x}$

  with $x = e^{-n_{pe}/N_{total}}$, C=0.25 and N_{total}=1156
- Generate signal randomly: $n_{pixel}^{new} = \mathrm{Gaus}(n_{pixel}, \sigma_{pixel})$ where $\sigma_{pixel} = 3 \ (\approx 0.2\mathrm{MIP})$
- Convert to MIP again $N_{MIP}^{new} = \dfrac{N_{total}}{N_{pe/MIP}} \cdot \ln\left(\dfrac{N_{total} - C \cdot n_{pixel}^{new}}{N_{total} - n_{pixel}^{new}}\right)$
- Add gaussian noise (MIP/Noise ~ 5)
- Produce digis if #ADC>4 (1 MIP, although in the next slide will show #ADC>2)

- **Next steps**
  - include 3x5 ns pre-time samples + 4x5ns in-time samples
  - in-time – time of arrival from the center of the detector
  - Can be used for time studies

Global compensation for pion response

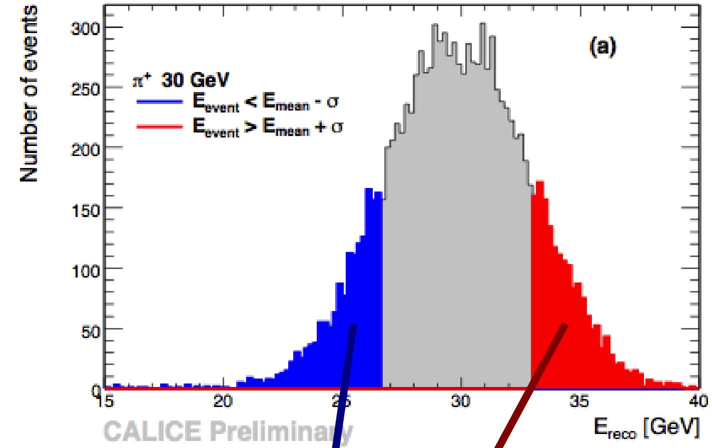
- Identify on an event-by-event basis the e.m. contribution
  - higher energy density expected for e.m. showers
  - different hit spectra for the e.m. content
  - apply global correction factor if e.m. fraction large
  - original method described in detail in CALICE AN 028 - link

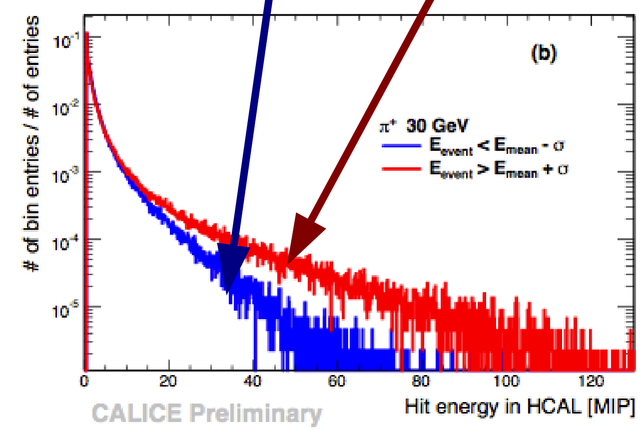
- Threshold is tuned to work for all energies
  - ~5 MIP is a good choice
  - use average energy per hit to define global correction factor

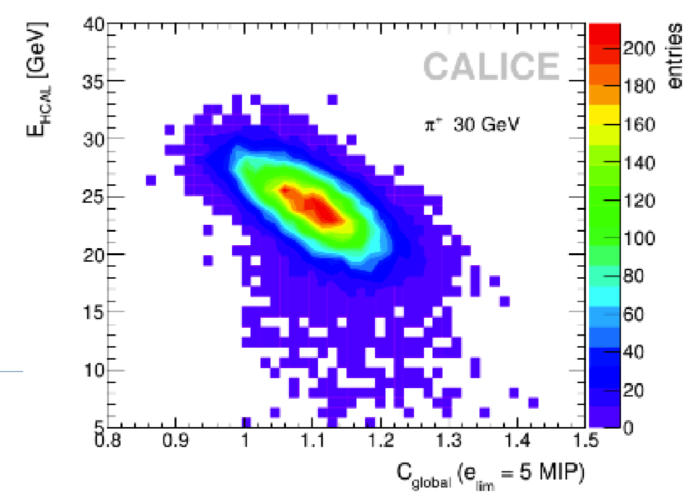
$$\boxed{C_{global} = \frac{N_i(e \leq e_{lim})}{N_i(e \leq e_{av})}}$$

  - C_{global} is anti-correlated with total reconstructed energy

    → use as correction factor: $\mathbf{E_{shower} = E_{rec} \times C_{global}}$
  - e.m. fraction (C_{global}) increases (decreases) with pion energy



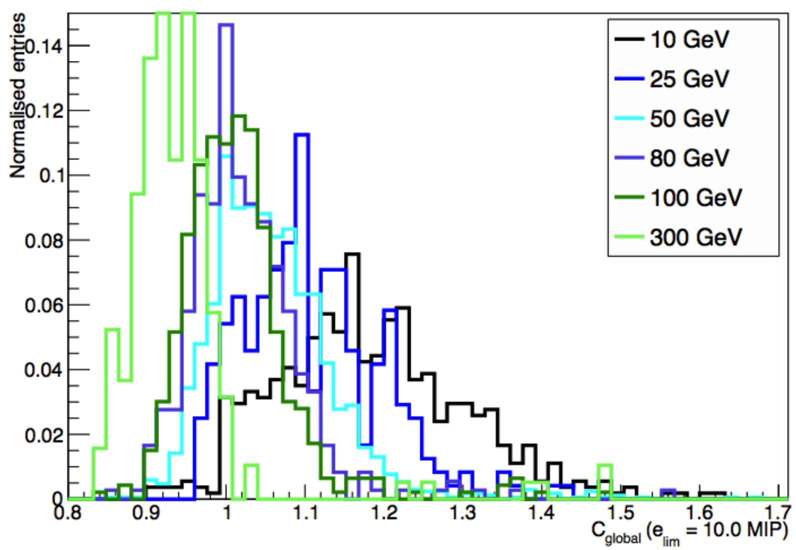


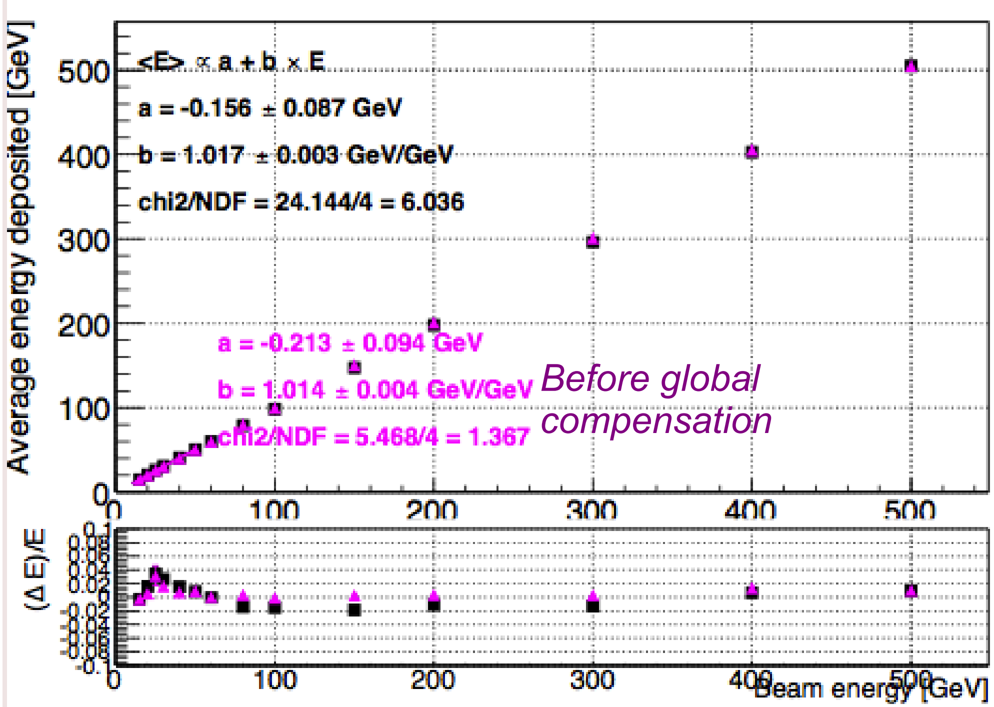


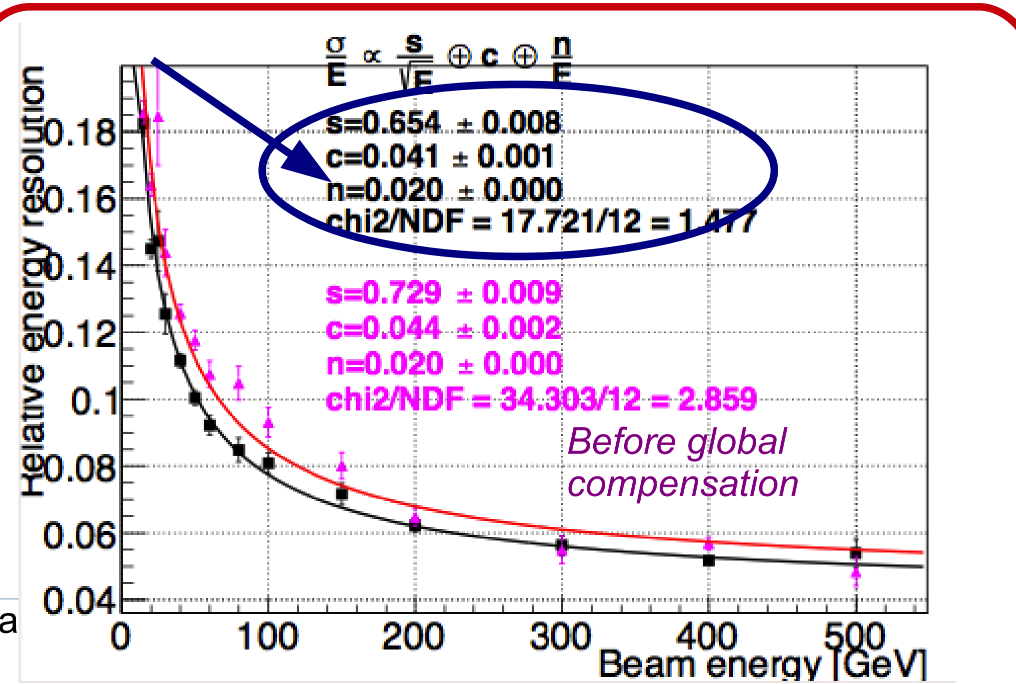
CALICE → HGCal

A.-M. Magnan

- Using latest geometry
- Repeat calibration procedure as for CALICE
- Increase energy range up to 500 GeV
  - e_{lim}=10 MIP found to be better performing
- Global compensation affects mostly low E
  - observe gain in the resolution
  - **stochastic/constant terms ~ 65% / 4%**

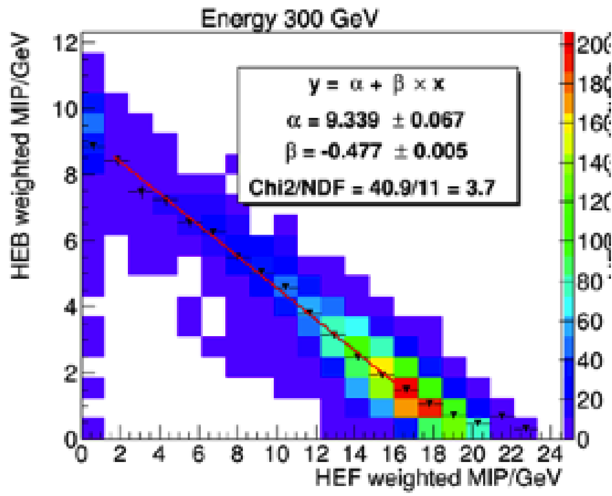




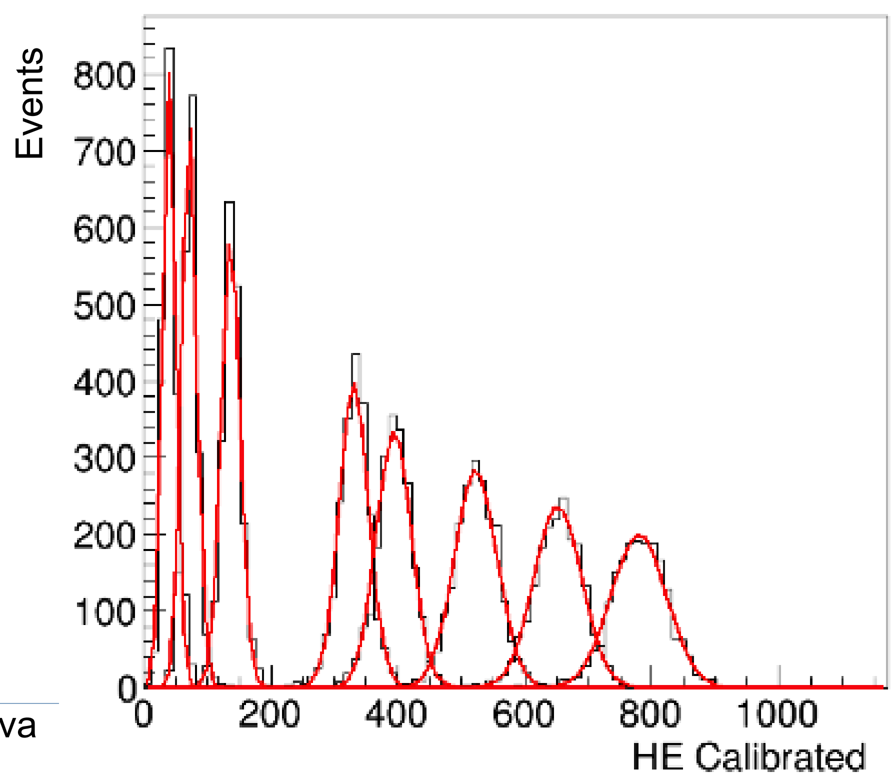


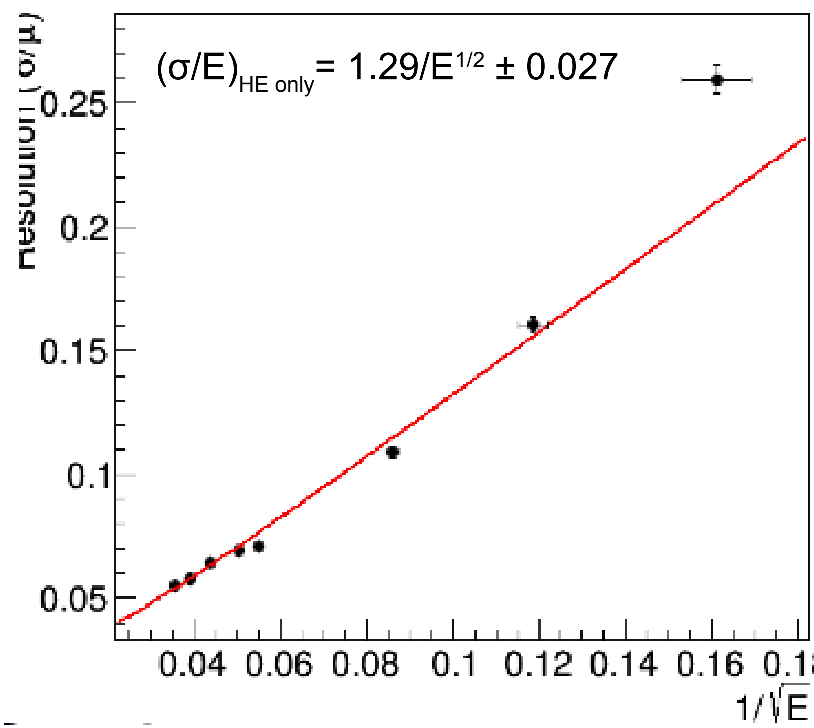
Standalone → CMSSW

- Analysing μ, e, K^0_L and π^+ samples
  - full geometry and **removing EE**
  - ECAL contribution is non-negligible (enhanced by n moderator effect)
  - linear calibration obtained for HE : 19.85 λ-weighted MIP / GeV
  - Relative response: HEF/HEB = 0.46 ± 0.002
  - Work in progress to complete full calibration with EE



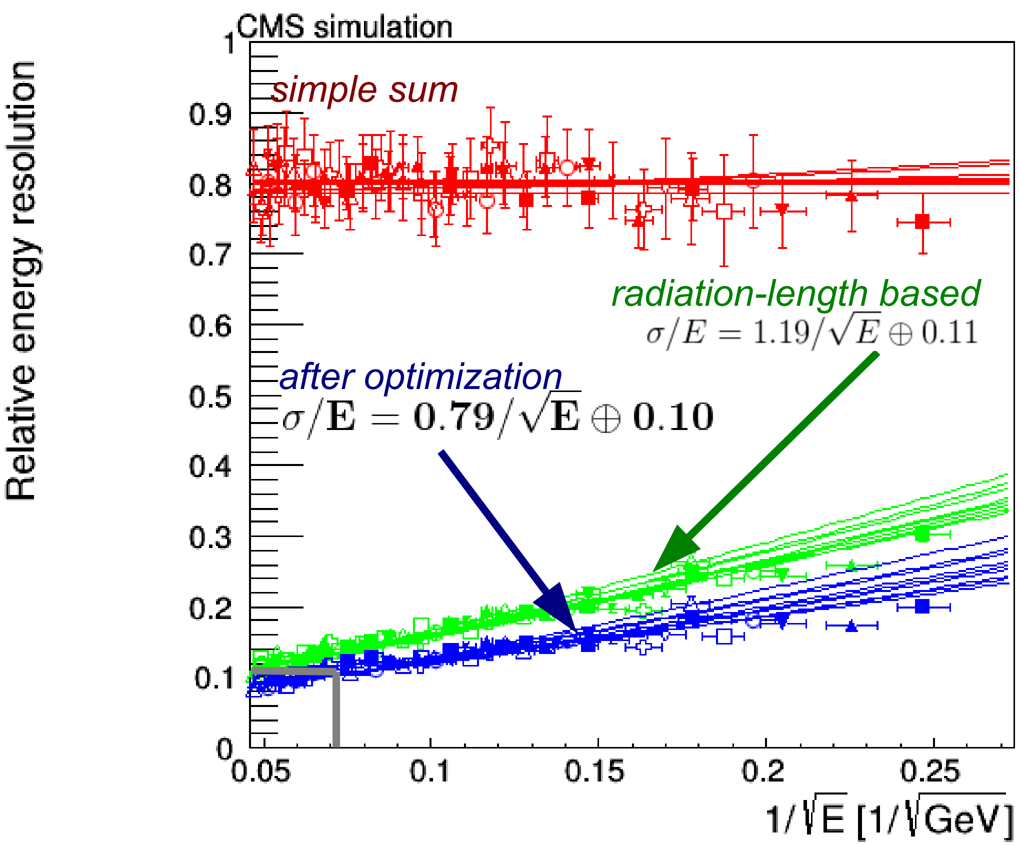
P. Hansen





Towards PF calibration - I

- While work on calibration is being refined and cross-checked....
- Provide PF developers with minimal calibration setup, to start testing algorithms
  - needed for tracker-cluster linking, PF object energy estimation, re-clustering...
- Apply a linear regression to a weighted sum of energy deposits per layer
  - baseline weights are absorber interaction length (radiation length for e/γ)
  - after correcting for η differences, minimize: $\Delta^2 = \sum_{k=1}^{N_{events}} \left(\sum_i w_i E_i + b - E_{beam} \right)^2$ @ SimHit level



π^+

Weights	EE				HE front	HE back	Offset
	1	2-11	12-21	22-31	1-12	1-10	
Baseline	0.0280	0.0650	0.1050	0.1600	1.0000	1.6670	
Optimized	0.0113	0.0110	0.0077	0.0169	0.0896	0.1068	6.7677

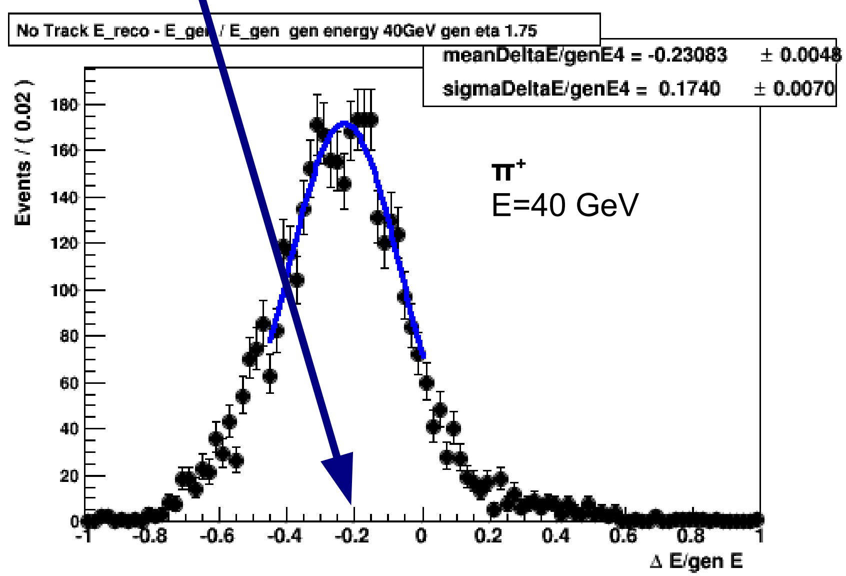
K^0_L

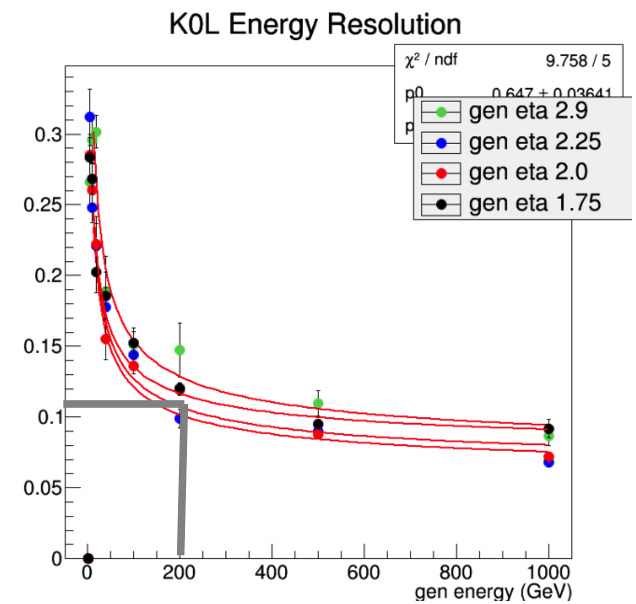
Weights	EE				HE front	HE back	Offset
	1	2-11	12-21	22-31	1-12	1-10	
Baseline	0.0280	0.0650	0.1050	0.1600	1.0000	1.6670	
Optimized	0.0060	0.0113	0.0075	0.0168	0.0902	0.1051	6.8727

Towards PF calibration - II

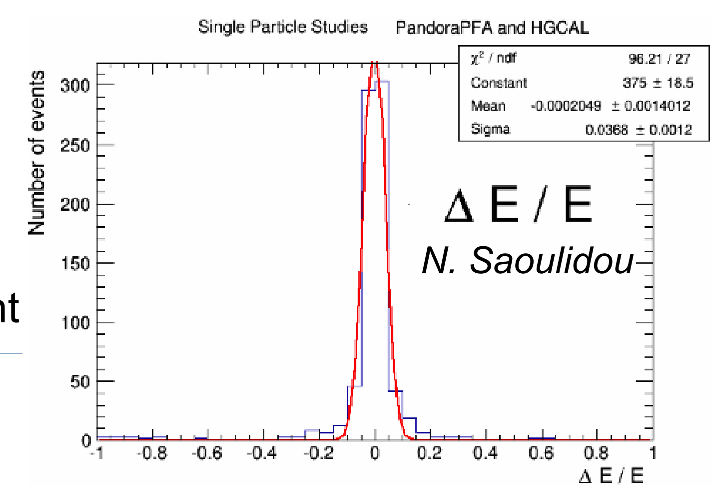
- First results using CMS PFCandidates, i.e. after clustering and linking
  - use the summed calorimeter-only energy of all PF candidates in a particle gun event
  - Find similar resolution to the one expected from the simple minimization scheme
  - However offset observed and also non-linearity at low energy

S. Kalafut





- Pion candidates reconstructed with Pandora as well
  - out of the box values ~90% PID efficiency
  - inc. resolution ~3.7% (20-100) GeV taking track into account



Conclusions and outlook

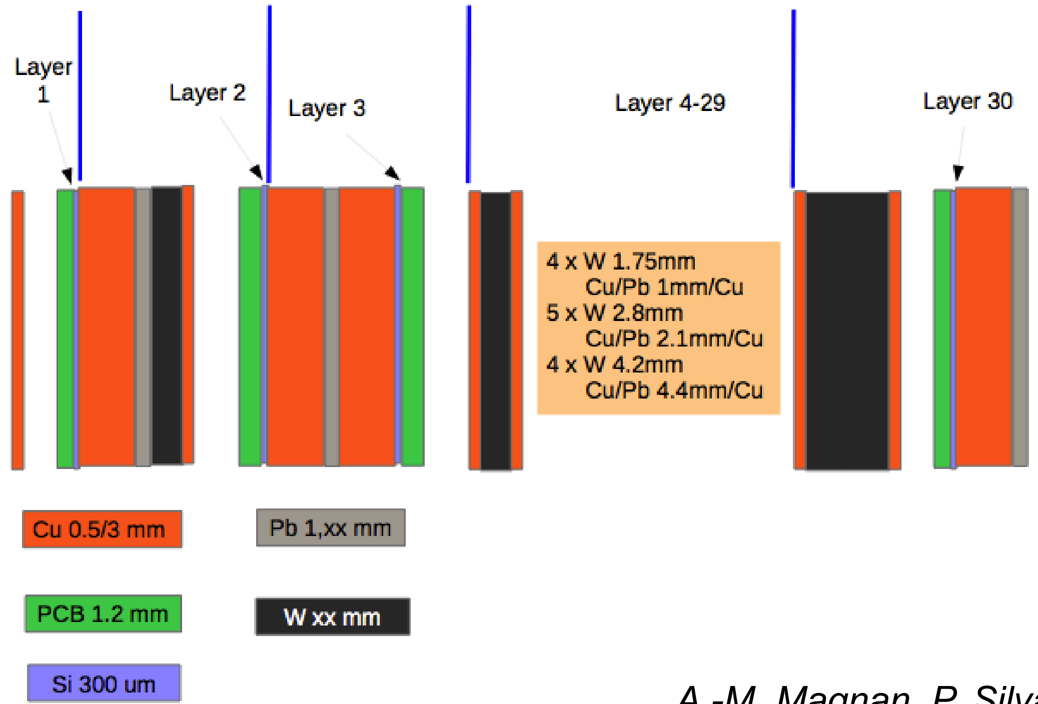
Conclusions and outlook

- **Overview of current efforts** in studying particle response in HGCal software group
- **Validation** implies starting **from a benchmark**
  - CALICE projections/measurements chosen to validate standalone simulation
  - HGCal implementation in standalone simulation to validate CMSSW results
- **First results** look **coherent and promising**
  - still much work ahead of us in understanding the details and commissioning simulation
  - currently concentrating on hadronic response calibration → needed for jets
- **Near future**:
  - <u>finalize pion calibration in CMSSW with global compensation scheme</u>
  - study longitudinal and transverse shower properties, hit multiplicities
  - compare different Geant4 physics lists (use in future to compare with test beam data)
  - explore pileup subtraction techniques already at RecHit level: e.g. use PUPPI metrics

Backup

e/γ resolution

- Update for latest geometry ▶
  - include 2mm and 4mm air gap versions
- Expected resolution is unchanged
  - Marginal dependency on air gap



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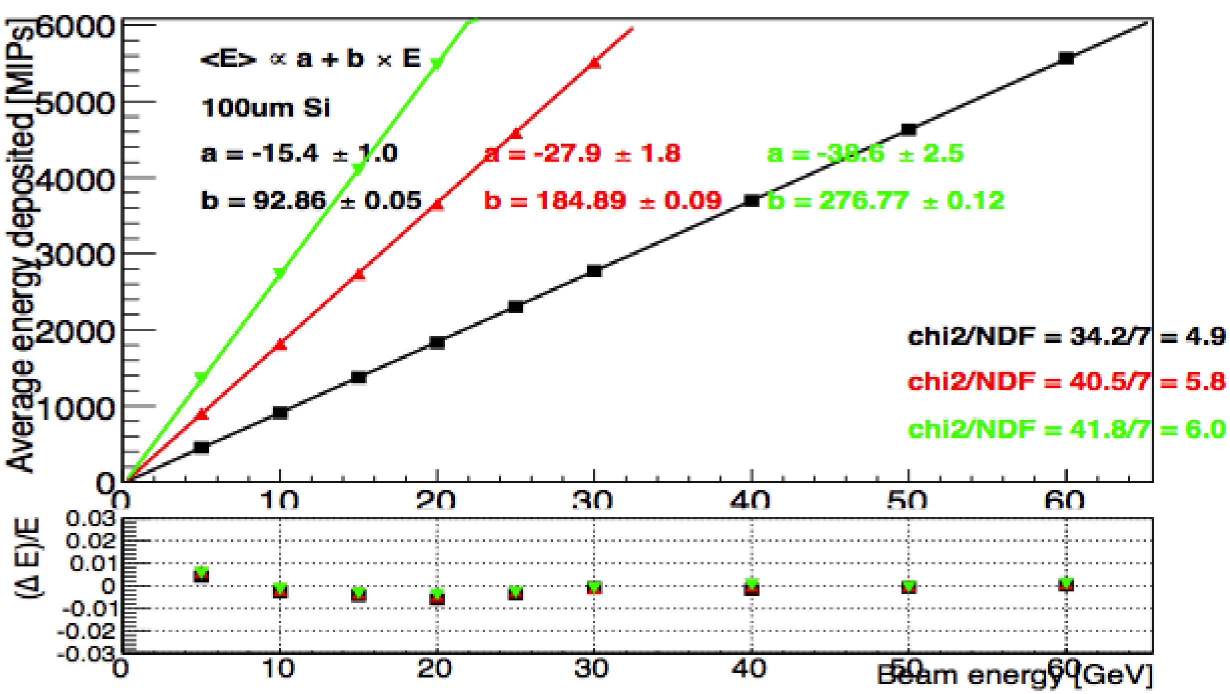
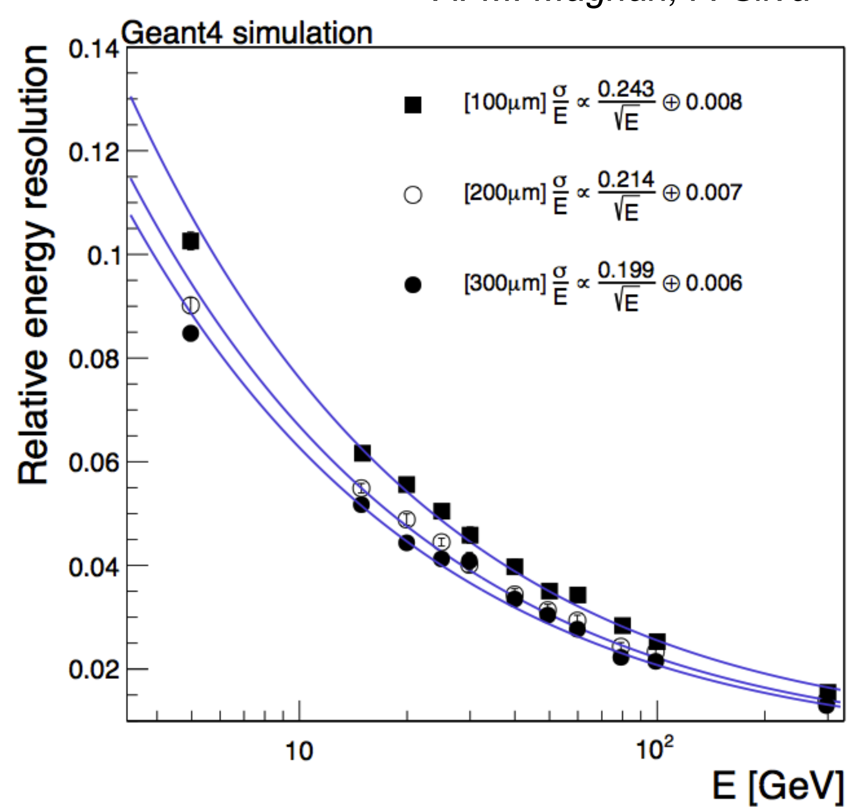
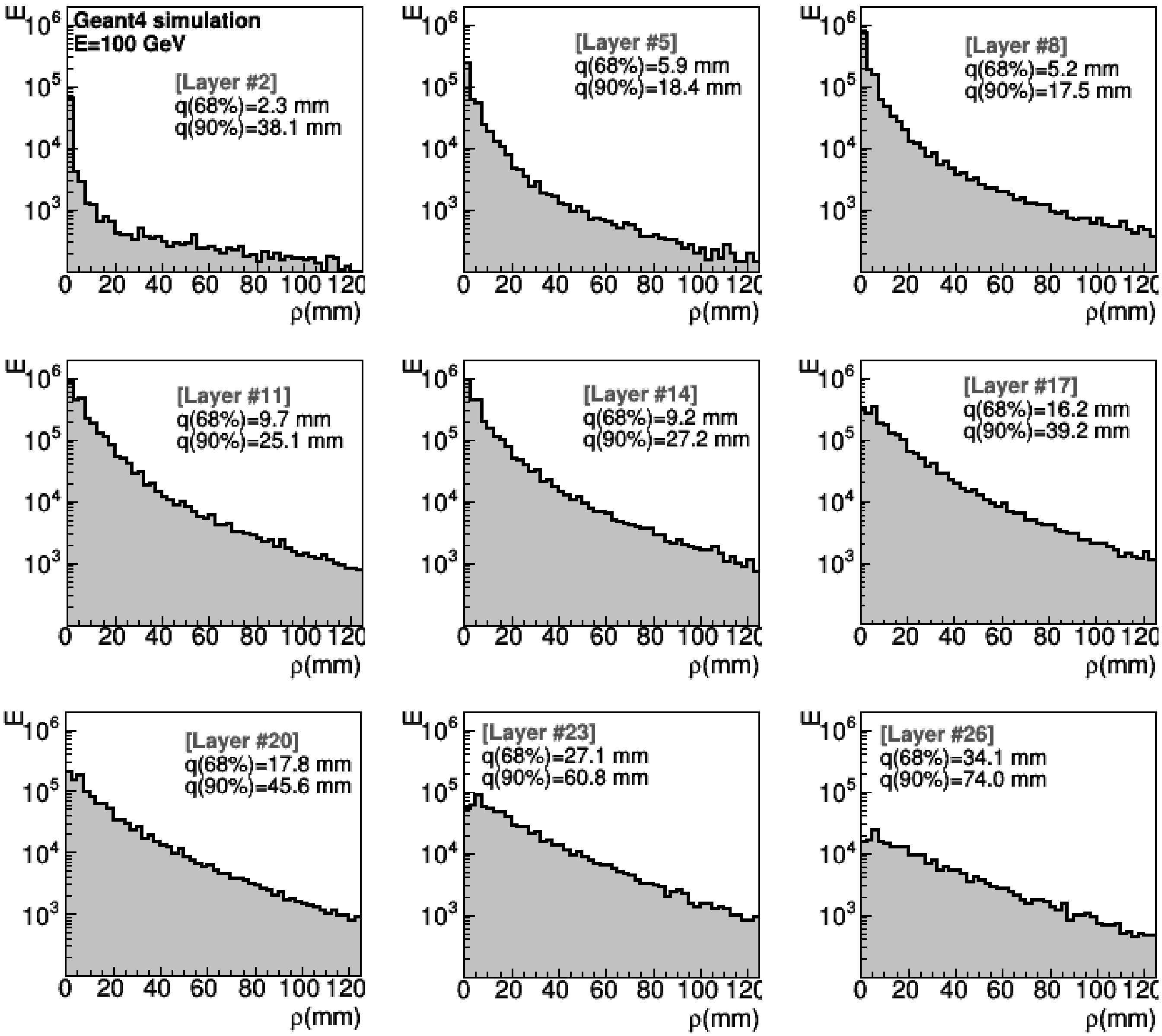
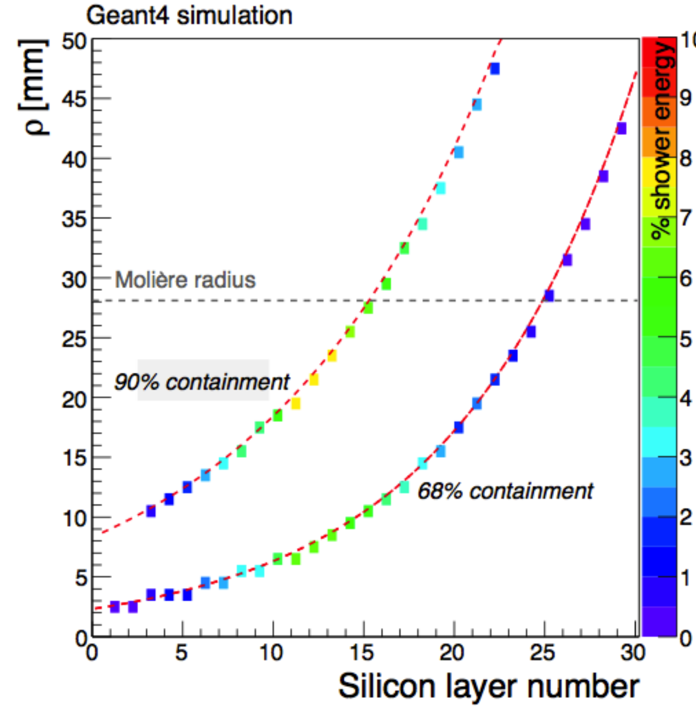




e/γ profile in the transverse plane





- EM showers considerably narrower than R_M before shower max
- After shower max dominated by beam halo (diffuse energy deposits)